Disturbance of Soil Organic Matter and Nitrogen Dynamics: Implications for Soil and Water Quality (CS-1114D-00)

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SEMP Research Coordination Meeting &
Technical Advisory Committee Meeting
October 28, 2002

Oak Ridge National Laboratory, managed by UT-Battelle, LLC, for the U.S. Department of Energy under contract DE-AC05-00OR22725

Background Slides

- Science Questions
- Research Goals
- Research Task
- Technical Background
- Measurements and Methods
- Year 1 - Disturbance Gradient
- Year 1 - Particulate Organic Matter
- Year 2 - Land Cover Differences
- Year 2 - Forest Clear-Cuts
- Year 2 - K-11 Studies
- Year 2 - Restored Sites

Science Questions

- Can soil carbon and nitrogen dynamics be used to identify nutrient resource thresholds to recovery of desired future conditions at Fort Benning?
- How do disturbances associated with military activity and forestry affect measures of soil quality?
- Which soil attributes and processes are good candidates for indicators of ecosystem disturbance and the identification of thresholds to recovery or

Research Goals

- Develop a better understanding of the effects of disturbance on key measures of soil quality (e.g., soil carbon and bulk density)
- Determine if there are thresholds to soil quality that affect ecosystem recovery or sustainability (i.e., critical levels of soil

Research Tasks

1. ***Characterize the effect of disturbance and land cover*** on key measures of soil quality (completed in 2002)
2. ***Determine thresholds*** that establish the potential for recovery of soil quality following site disturbance (continuing effort)
3. ***Build simple dynamic models*** for different land cover categories to predict recovery of soil quality on disturbed land (continuing effort)
4. ***Field experiments*** to calibrate models used to predict the recovery of soil quality (continuing effort)
5. ***Spatial analysis of soil C and N dynamics*** to

Technical Background

- Soil C and N dynamics, along with texture and structure, are determinants of soil quality (i.e., the ability of a soil to function in its natural condition or the suitability of soil for a particular use).
- Land use and land use change can affect soil C and N dynamics.
- Military activities can impact soil properties (chemistry and structure), root development, and ultimately plant community composition.
- We presently have a poor understanding of soil quality thresholds that may affect ecosystem

Measurements and Methods

- Profiles of soil C and N concentrations (%) and stocks (g m^{-2})
- Estimates of soil bulk density (g cm^{-3}) (indicator of soil compaction)
- Extractable soil N and potential soil N mineralization rates
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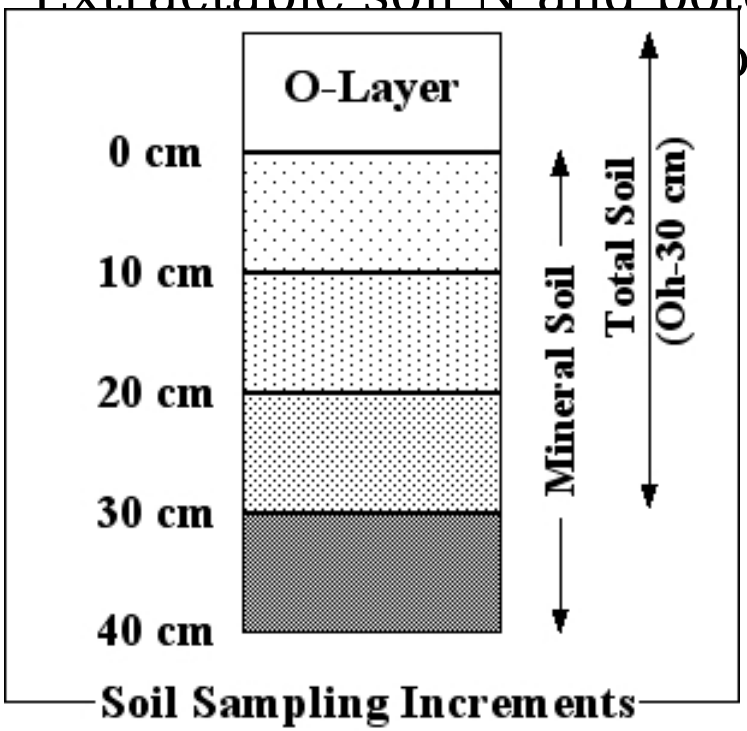
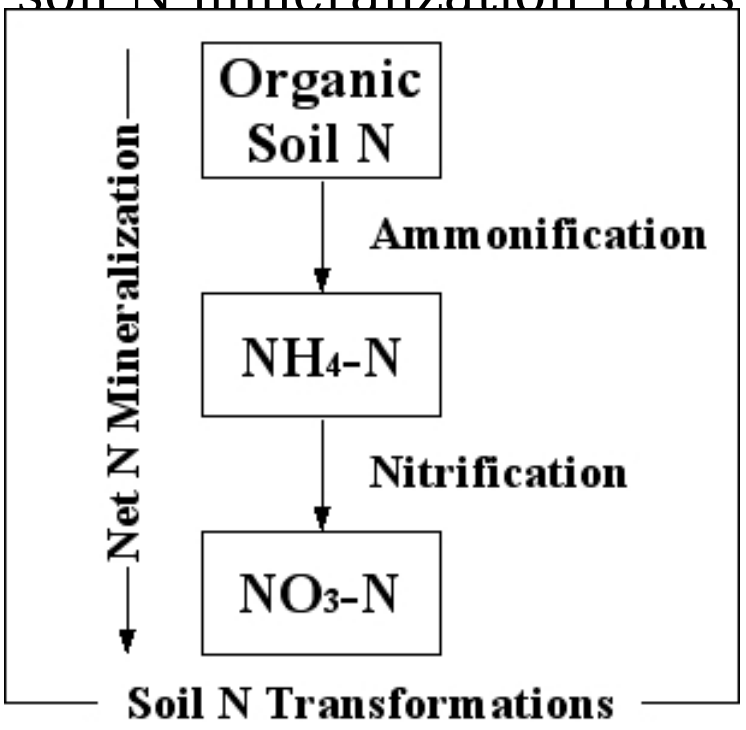
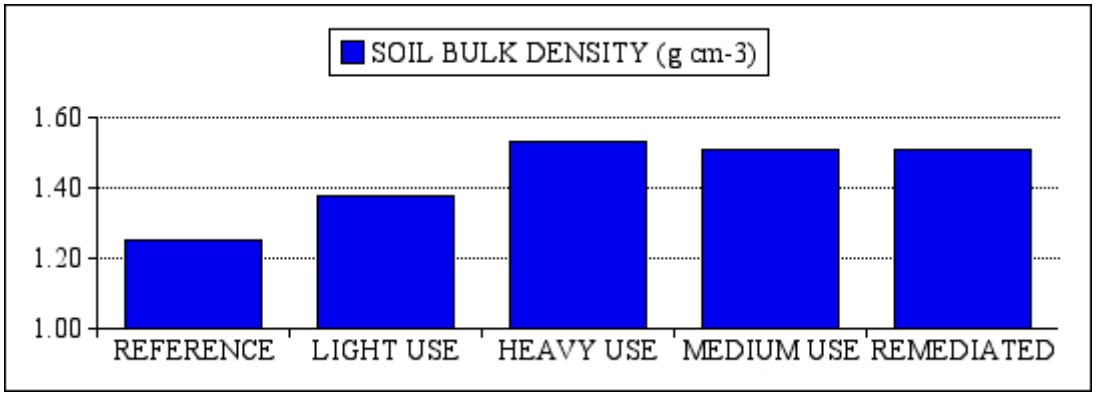
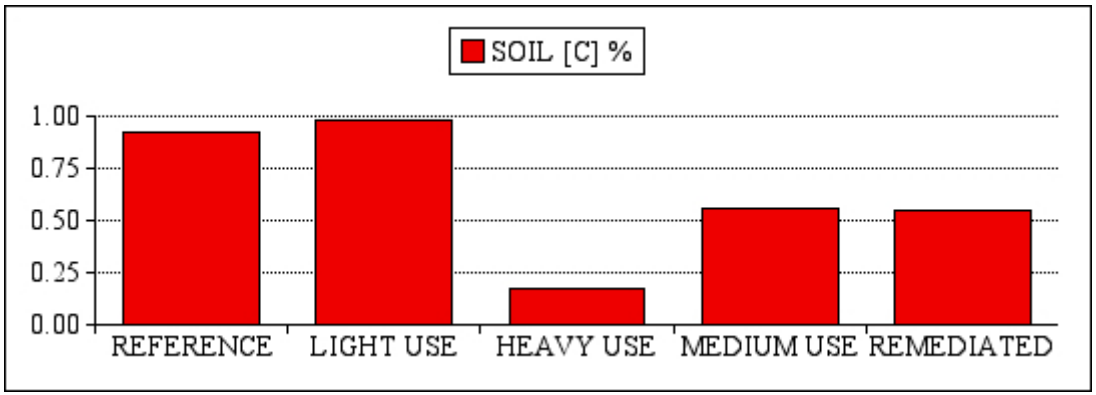




Year 1 - Disturbance Gradient

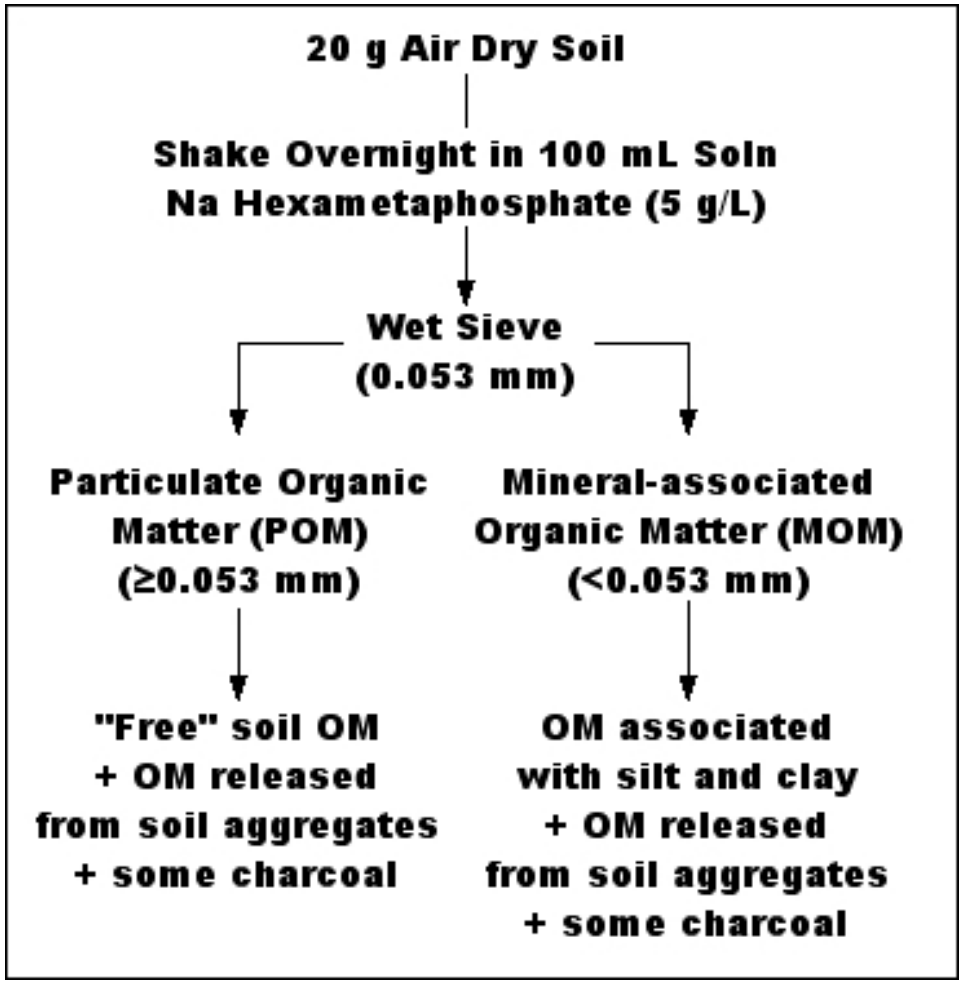
- Surface soil bulk density increased along the disturbance gradient and the change persisted at remediated sites.
- Surface soil C stocks and soil C:N ratios declined along the disturbance gradient.





- With the exception of surface soil bulk density, measured soil properties at reference and light use sites were similar.
- There was some indication of recovery in soil C stocks at remediated sites.
- Measurements related to C and N are indicators of changes in soil quality.

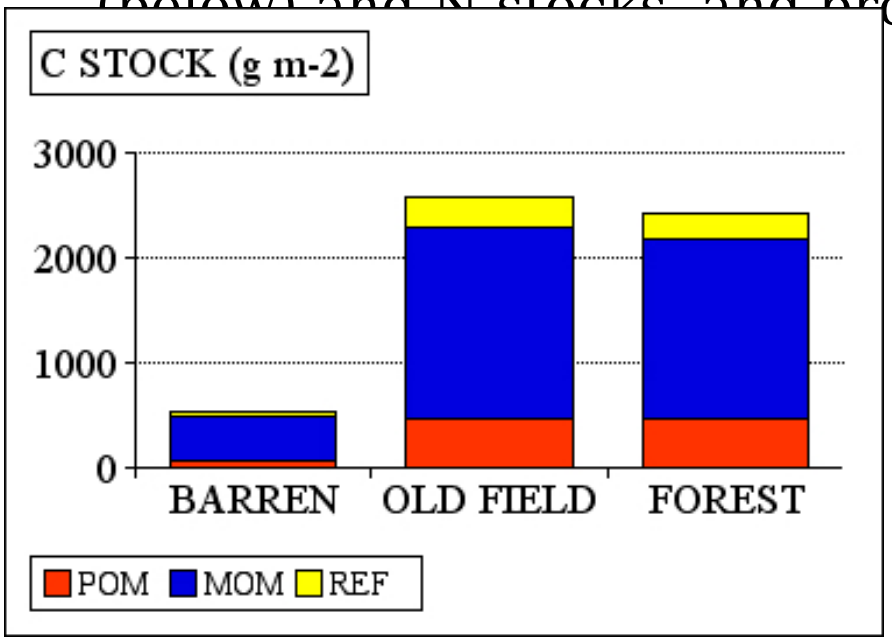
Year 1 - Particulate Organic Matter



- POM-C is a labile pool consisting of free organic matter and larger organic debris released after dispersion of soil aggregates (short turnover time is temperature dependent)
- MOM-C is a more stable pool of soil C associated with silt and clay (humics) and includes smaller

Year 2 - Land Cover Differences

- Sampling sites classified into 5 land cover types: barren land, transitional vegetation, evergreen forest/plantation, mixed, and deciduous forest
- Land cover has a significant effect on key measures of soil quality including soil bulk density, soil N availability, soil C (below) and N stocks, and properties of the O-horizon



POM = particulate OM

MOM = mineral-associated OM

REF = refractory OM

- Barren land has poor soil quality relative to other land cover types
- The presence of long-term perennial vegetation is

Year 2 - Forest Clear-Cuts

Mean (C.V.) Soil Properties Along a Gradient

Land Cover (n)	Years since cut	Oh-30 g C/m^2	BD 00-10 cm (g cm^{-3})	Initial extractable (μg N g^{-1})	Net N min. (yr^{-1})	NO3-N prod. in 12 weeks (μg g^{-1})
Control forests (12)	--	3710 (0.20)	1.06 (0.07)	2.99 (0.50)	0.031 (0.95)	2.11 (1.94)
Clear cut forests (2)	1	3711 (0.14)	1.29 (0.13)	5.90	-0.018 (2.90)	11.9 (1.41)
Old field (4)	6	2833 (0.27)	1.19 (0.14)	2.45 (0.82)	0.031 (1.92)	2.00 (1.46)
Recovering forest (4)	11	2941 (0.31)	1.18 (0.08)	2.43 (0.67)	0.007 (3.70)	0.48 (1.39)
Mature pine (10)	--	3843 (0.27)	1.16 (0.16)	2.27 (0.72)	0.025 (1.25)	1.15 (1.53)

Control Forest

Clear-cut

One Year Later

- Field data indicate a temporary decline in soil C stocks and an increase in soil N availability after clear-cutting (increased abundance of N_2-fixers)
- Variation is large, but the potential rate of net soil N mineralization at undisturbed

Year 2 - K-11 Studies

Mean (C.V.) Forest Soil Properties in Upland and Near Stream Environments

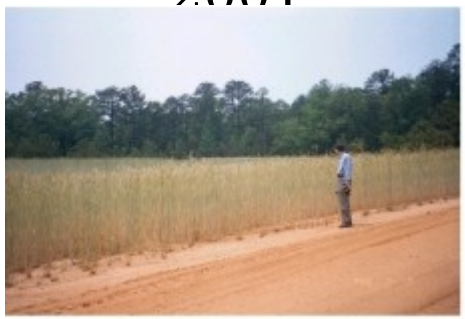
Landscape position	n	Oh-30 cm g C/m^2	Oh-30 cm g N/m^2	Initial extractable soil N (µg N/g)	Net N min. rate (yr^{-1})	NO_3-N prod. in 12 wks (µg N/g)
Near stream	15	6064 (0.25)	184 (0.30)	4.2 (0.49)	0.09 (0.53)	9.9 (1.24)
Upland	18	3227 (0.18)	94 (0.33)	1.4 (0.45)	0.02 (1.57)	1.4 (1.21)

Near Stream Site

Upland Site

- Soil C and N stocks, and soil N availability is greater in the near stream environment than in the upland environment at K-11 (pre-treatment sampling).
- Assuming an annual litterfall of 408 g m^{-2} (Sharpe et al., 1980), the estimated annual soil C input is 367 g C m^{-2} and the estimated turnover time for soil C is 8.8 and 16.5 yrs, respectively, at

Year 2 - Restored Sites

	SPRING 2000	SPRING 2001	SPRING 2002
ECHO AREA	174 g C m^{-2}	 225 g C m^{-2} (29% Increase)	278 g C m^{-2} (60% Increase)
DELTA AREA	490 g C m^{-2}	840 g C m^{-2} (71% Increase)	842 g C m^{-2} (72% Increase)

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Progress FY 02

- Project Flowchart
- Year 3 - Longleaf Pine Chronosequence
- Year 3 - Modelling
- Threshold Concept
- Modelling Approach
- Model Calibration
- Spreadsheet Model Input
- Spreadsheet Model Output
- Spreadsheet Thresholds
- Stella(R) Model
- Soil Carbon Turnover
- Scenario: Forest Management
- Scenario: Community Change
- Scenario: Forest Recovery
- Conclusions From Modelling
- Research Products
- Research Accomplishments
- Future Plans

Project Flowchart

Predict System Response to Disturbance and Identify Thresholds to Recovery

Build mathematical models:
1. spreadsheet models (simple)
2. compartment modelling (complex)

Field measurements from:
1. disturbance gradients
2. different land cover categories
3. forest chronosequences

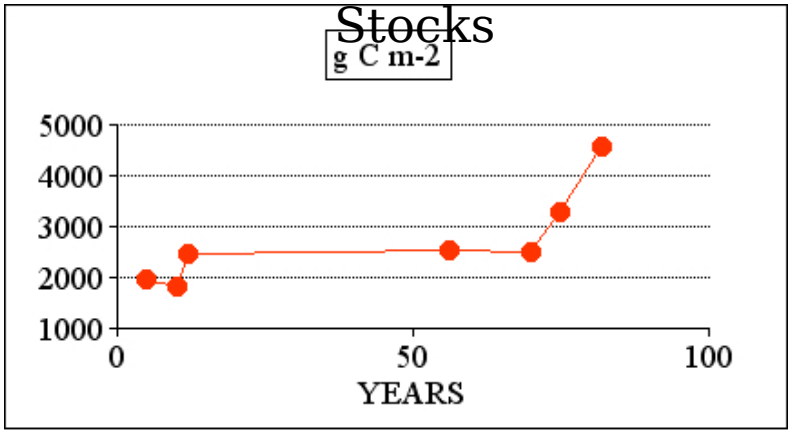
Landscape level analysis of soil C and N dynamics (GIS data + field data + modelling)

Year 3 - Longleaf Pine Chronosequenc

Data from longleaf pine chronosequence (Spring 2002)					
Stand Age in Years [ID code]	Basal Area (m^2/ha)	Foliage (g/m^2)	Estimated Litter fall (g/m^2)	AGBD (g/m^2)	Estimated C Input to Soil (g/m^2)
5 [K17Y]	0.20	7.4	4.2	--	3.8
10 [161-NR]	17.1	626	357	--	321
12 [T5Y]	13.2	483	275	--	248
56 [G5M]	18.7	684	390	14147	351
70 [G5A]	26.3	962	548	19687	494
75 [A14A]	29.9	1093	623	24072	561
82 [K17A]	17.2	631	360	14074	324

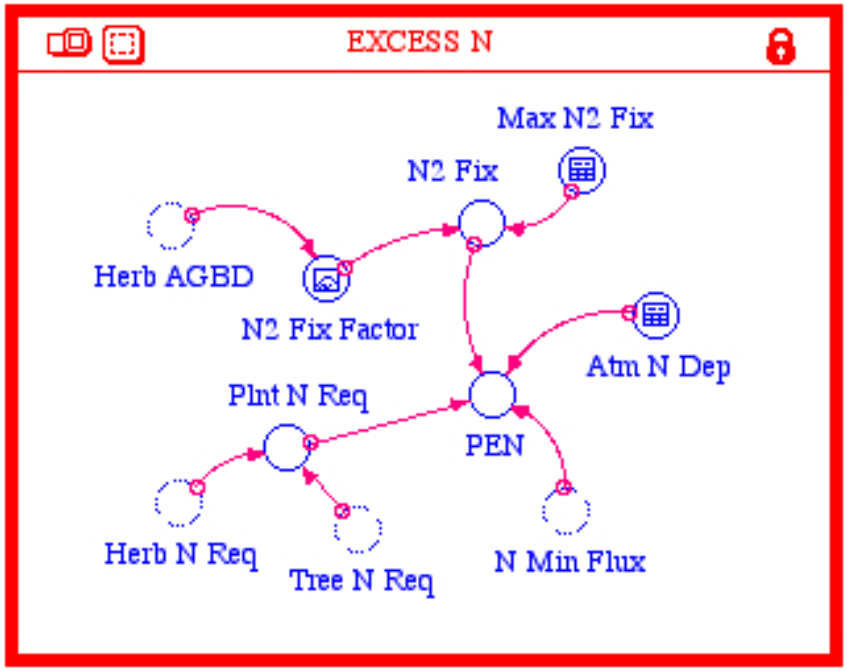
- The average AGBD in mature longleaf pine stands was 17995 g m^{-2} (C.V. = 0.27)
- Soil C and N stocks and the fraction of soil C in particulate organic matter were highest in the two oldest for

Change in Mineral Soil C Stocks



Year 3 - Modelling

- Advantage - modelling can be used to predict the response of an indicator over a range of hypothetical disturbance levels

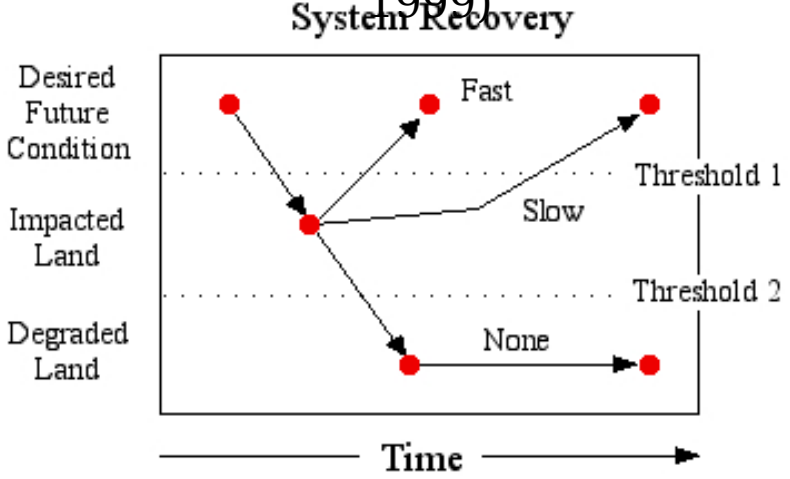


Submodel for Potential Excess N

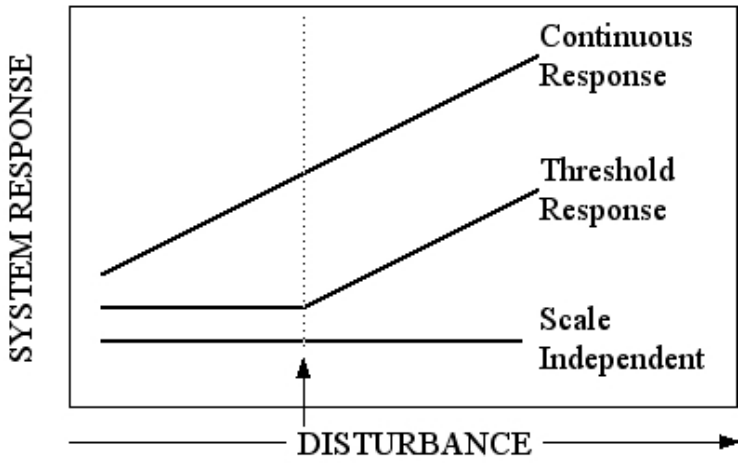
- Advantage - models are a framework for integrating information and feedbacks.
- Disadvantage - modelling depends on the availability of appropriate data (model what is measurable).
- Disadvantage - do we know enough about the

Threshold Concept

SEMP Workshop Concept (Nov 1999)



Adapted from Romme et al. 1998. Are large, infrequent disturbances qualitatively different from small, frequent disturbances? Ecosystems 1: 524-534.



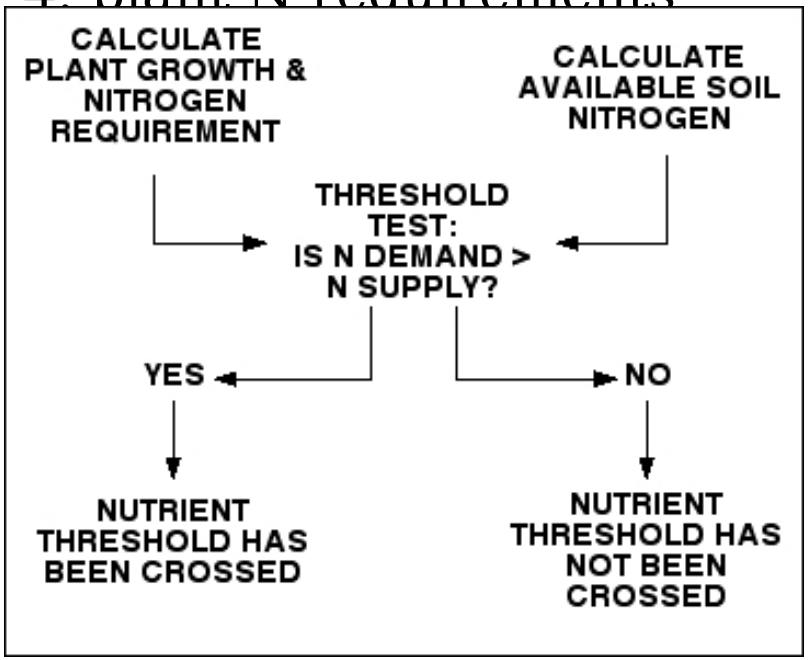
- Prepared white paper that reviewed the concept of ecological thresholds for the TAC
- Threshold is the point that separates something true from something not true, or the point at which there is a discernable effect or change in behavior in response to a stimulus (or disturbance)
- “Sudden change in any property of an ecological system as a consequence of smooth and continuous change in an independent variable” (Muradian 2001)
- SREL and ORNL Team 2 are studying thresholds of ecosystem sustainability and potential for recovery within a unified concept that includes changes in biogeochemical cycling and the structure/composition of plant communities

Modelling Approach

- The model asks the question: "Are soil nitrogen supplies sufficient to meet the nitrogen demands of growing biomass associated with a desired future ecosystem condition?"
- Issues related to management and restoration toward a desired future condition can be analyzed through the use of nutrient

Dynamic components include:

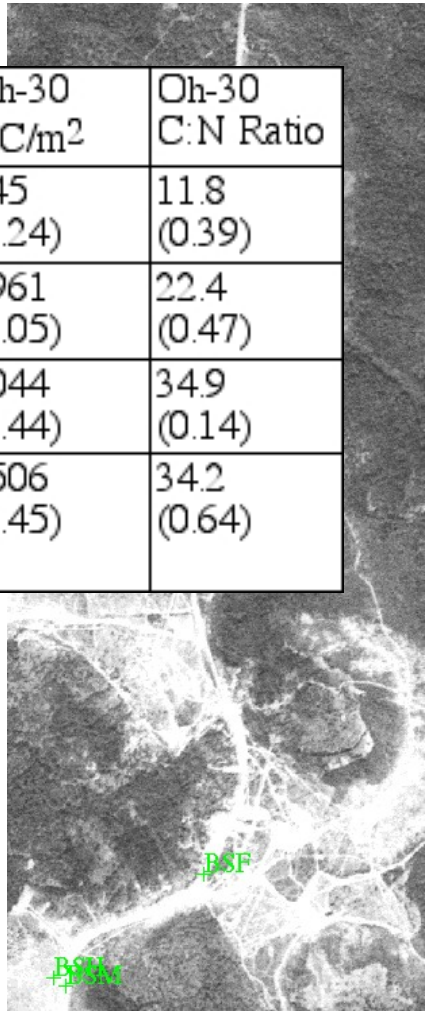
1. plant biomass
2. soil carbon
3. soil nitrogen
4. plant N requirements



Model Calibration

- Corona photographs from 1964 were used to identify changed and unchanged sites.
- 36 year old forests and 36 year old fields are similar in soil C stocks.
- Soil C:N ratios increase as succession proceeds from barren land to old field to forest.
- Sites with a known age are valuable calibration points for modelling recovery.

Land Cover	Sample size	Oh-30 g C/m^2	Oh-30 C:N Ratio
Barren (36+ years)	5	445 (0.24)	11.8 (0.39)
Old field (36+ years)	2	3961 (0.05)	22.4 (0.47)
Forests (36+ years)	5	4044 (0.44)	34.9 (0.14)
Pine forests previously barren in 1964	2	3506 (0.45)	34.2 (0.64)

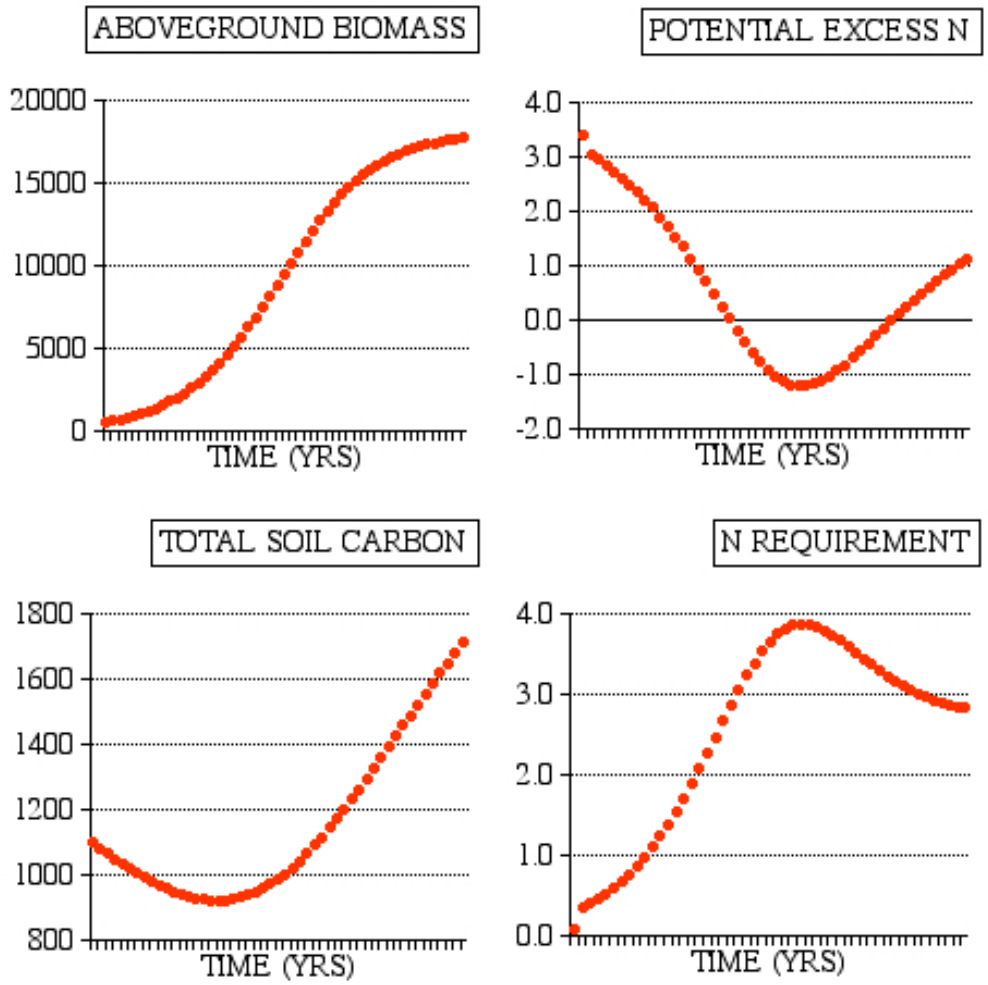


Spreadsheet Model Input

Parameters in the spreadsheet model. Numbers in parenthesis indicate relative sensitivity of potential excess N to a ±20% change in the default parameter value.		
BIOMASS DYNAMICS	NITROGEN DYNAMICS	CARBON DYNAMICS
AGBD (0.90)	Rate N mineralization (2.6)	Tissue [C] (2.0)
Recovery % (0.80)	Leaf [N] (1.1)	New soil C loss rate (14.6)
Growth rate (0.70)	Wood [N] (0.0)	Old soil C loss rate (2.3)
Root:shoot ratio (1.00)	Root [N] (0.0)	Initial soil C stock (2.3)
Foliar fraction (0.10)	Translocation factor (1.1)	Old soil C:N ratio (2.7)
Root turnover time (0.90)	N Deposition (0.3)	

- The spreadsheet model is similar to NuCSS (Nutrient Cycling Spreadsheet Model) described by Verburg and Johnson in *Ecological Modelling (2001*)
- Calculates plant N requirement independent of soil N availability and tests for point where PEN becomes negative (i.e., N requirement > soil N supply)
- Model predictions are most sensitive to a change in the

Spreadsheet Model Output

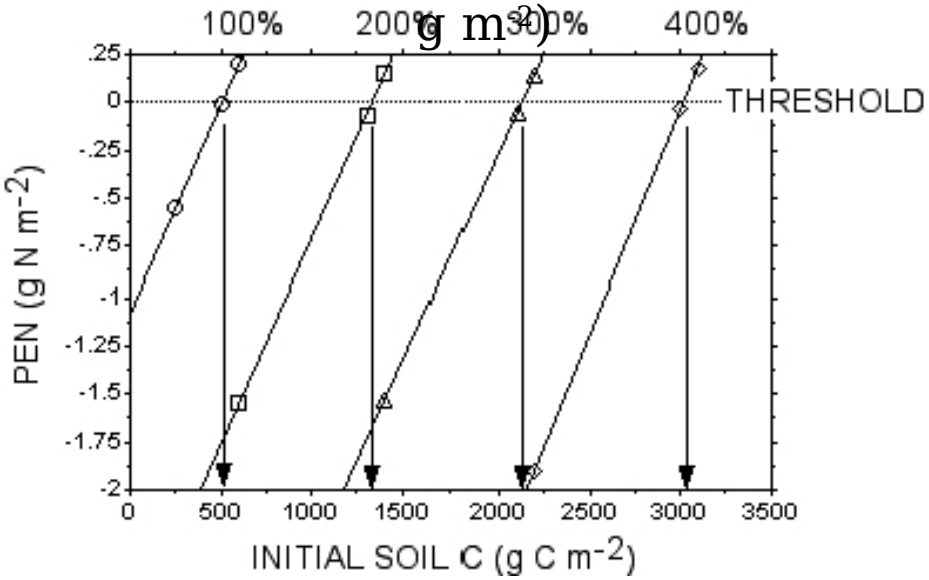


A 50-Year Simulation of Forest Recovery

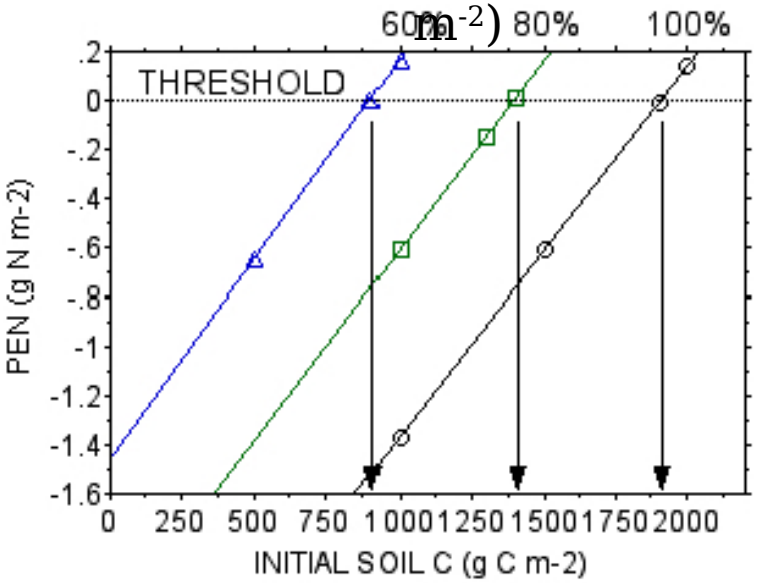
- Relatively simple approach
- Calculates above- and belowground biomass
- Separates new soil C (fast turnover - years) and old soil C (slow turnover - decades)
- Includes no feedback from available soil N to plant growth
- Models forest biomass or herb biomass (not both)
- Can be used to identify thresholds to recovery of desired future conditions

Spreadsheet Thresholds

Herbaceous Cover (350 g m^{-2})



Forest Cover (18000 g m^{-2})



- Threshold is set by potential excess N (>0 is okay but <0 indicates soil N supplies cannot meet plant N requirements -- deficiency)
- Threshold to recovery of herbaceous vegetation (350 g m^{-2}) is 500 g C m^{-2}
- A higher target for AGBD will increase the initial soil C stock required to reach the desired

- Threshold to recovery of forest vegetation (18000 g m^{-2}) is 1900 g C m^{-2}
- A lower target for AGBD will decrease the initial soil C stock required to reach the desired future condition (target AGBD)
- Recovery depends on the desired future condition (AGBD), initial soil quality (C stocks), and plant N

Stella(R) Model

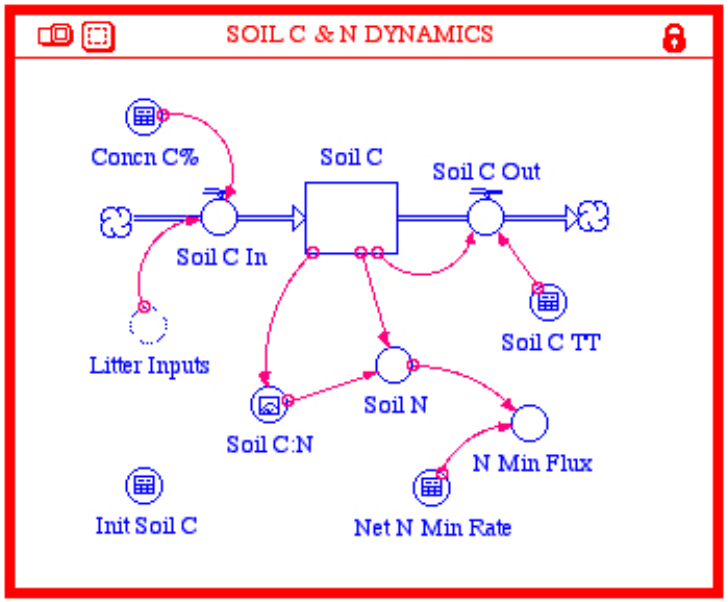
Parameters in the Stella® threshold model. Numbers in parenthesis indicate relative sensitivity of potential excess N to a ±20% change in the default parameter value.		
BIOMASS DYNAMICS	NITROGEN DYNAMICS	CARBON DYNAMICS
Foliar turnover (1.25)	N deposition (1.20)	Tissue [C] (1.85)
Foliar fraction (1.40)	Tissue [N] (7.65)	Soil C turnover (1.85)
Herb root:shoot (3.05)	Max. N2 fixation (3.20)	
Herb root turnover (2.75)	N mineralization rate (4.70)	
Herb translocation (1.25)		
Max. tree AGBD (3.00)		
Min. herb AGBD (1.00)		
Tree root:shoot (2.25)		
Tree root turnover (2.00)		
Tree target biomass (2.75)		
Tree translocation (3.95)		
Tree growth rate (0.00)		

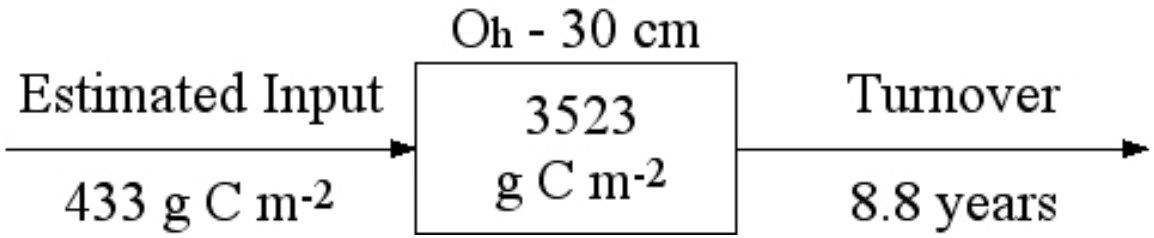
- Missing solid information on many critical parameters and processes (e.g., N translocation, N mineralization rates, root:shoot ratios)

- Annual time step
- Calculates above- and belowground biomass
- Includes a single soil carbon pool
- Parameter values derived from field data and literature
- Incorporates feedback from soil nitrogen to tree growth rate
- Overstory and understory

Soil Carbon Turnover

- Soil C turnover times are critical to modelling thresholds associated with soil N availability.
- Earlier versions of the Stella(R) model included two soil compartments but involved many assumptions.
- Latest model includes one compar
but few

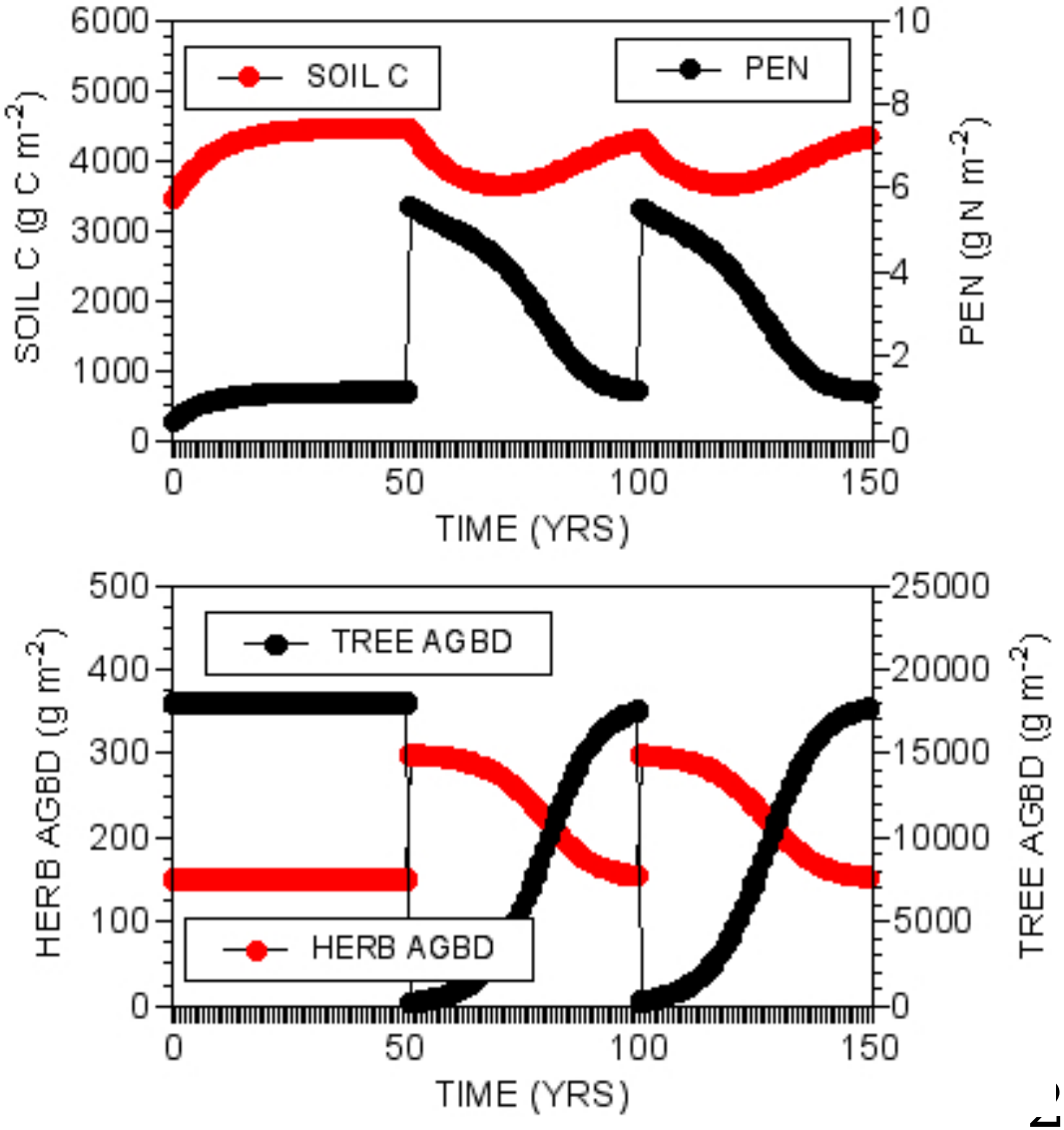




- Estimated soil C inputs from data obtained in mature longleaf pine stands.
- Soil C turnover (approximately 9 years) was calculated from 4 oldest sites.

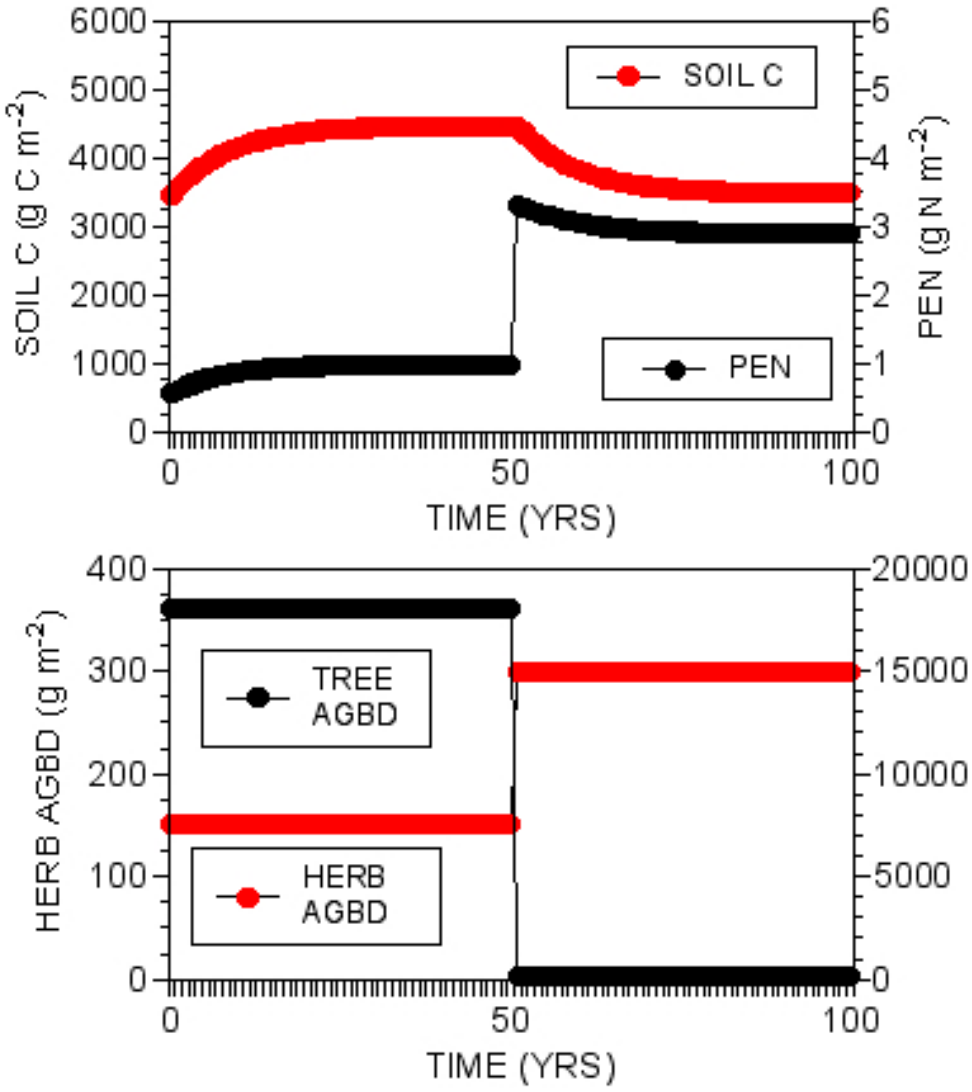
Scenario: Forest Management

- 50 year harvest interval
- Growth of herbaceous vegetation (HERB AGBD) is released by forest (TREE AGBD) removal
- Soil carbon stocks (SOL C) exhibit a temporary decline and then recover after forest harvesting
- Soil N availability (PEN) increases after forest harvest (less N demand)
- Model predicts that the system is



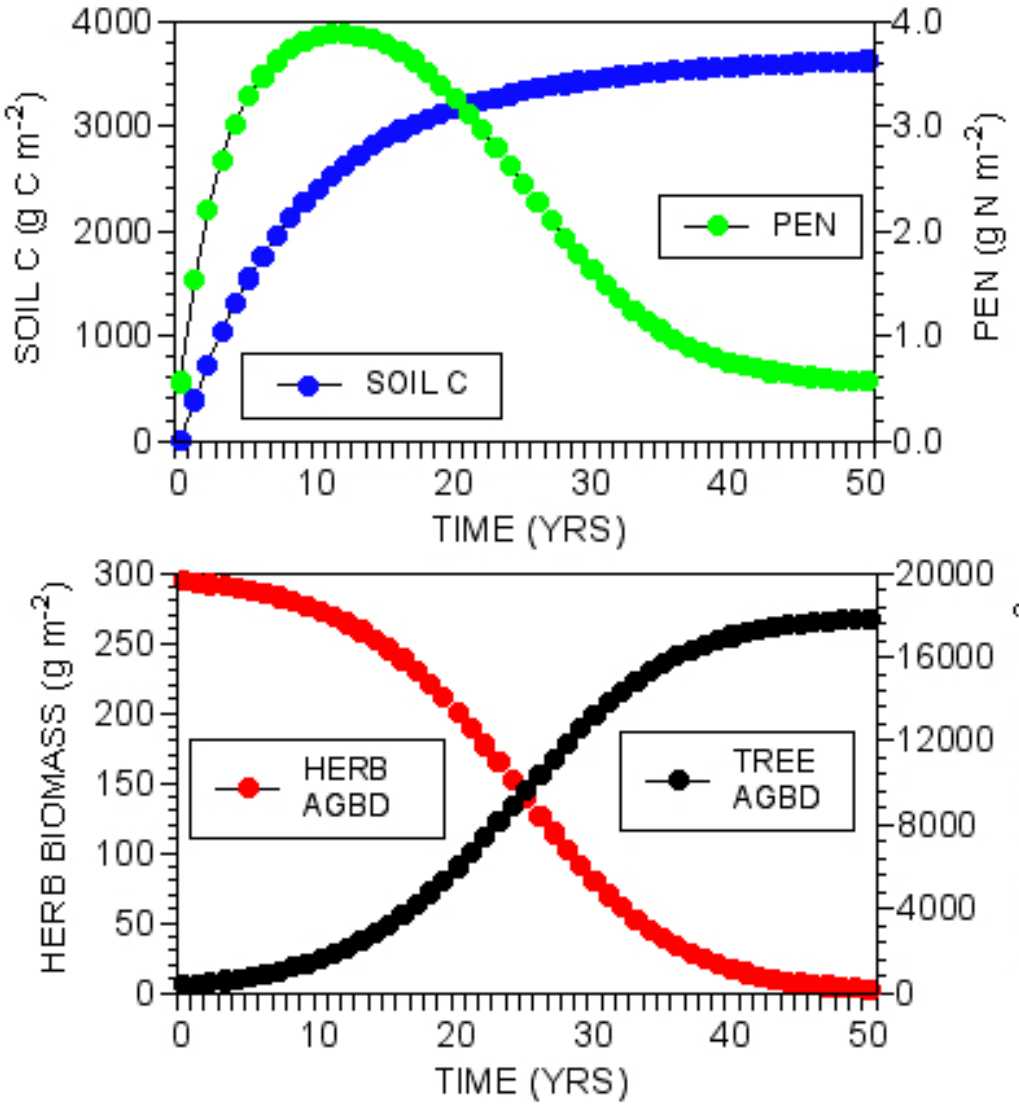
Scenario: Community Change

- 100 year simulation
- Forest biomass (TREE AGBD) was permanently replaced with herbaceous vegetation (HERB AGBD).
- Soil C stocks (SOIL C) declined to a new steady state (loss of O-horizon).
- Soil N availability (PEN) increased under herbaceous vegetation (increase in N_2-fixation).
- There is no dramatic



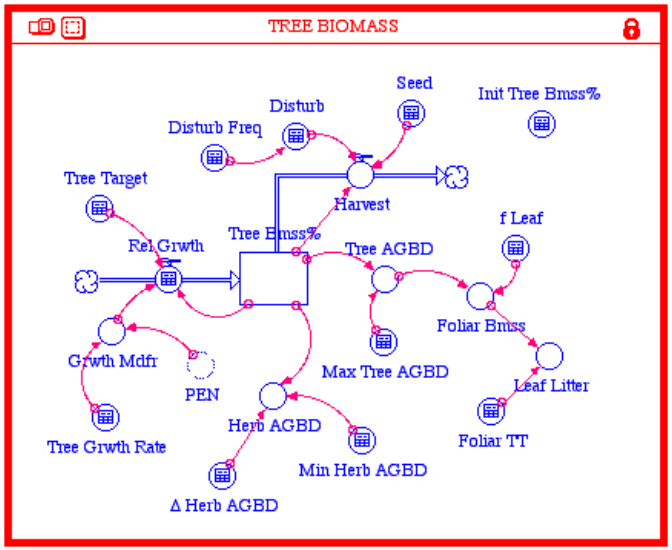
Scenario: Forest Recovery

- 50 year simulation
- Initial soil C stock was set to 0 g C m^{-2}
- Herb biomass (HERB AGBD) declined as tree biomass (TREE AGBD) increased.
- Soil carbon (SOIL C) increased and available soil N (PEN) declined with forest recovery.
- Thresholds to recovery are

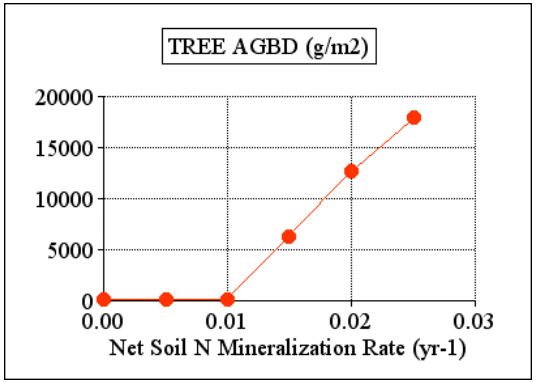


Conclusions From Modelling

- Model predictions for various scenarios are reasonable and consistent with available field data from Fort Benning.
- Thresholds predicted with the spreadsheet model are conservative.
- Thresholds predicted with the Stella(R) model depend on model structure.
- A better representation of forest growth, feedbacks from available soil N to forest growth rates, and edaphic controls on soil N mineralization is required.
- Both modelling approaches stress the importance of soil N availability.



Tree Biomass Submodel



Predicted threshold -- is it real?

Research Products

- **New basic information and understanding of soil carbon (amounts, vertical profiles, and various forms) and nitrogen dynamics (potential soil N transformations) under different land covers and disturbance regimes at Fort Benning, GA**
- **Mathematical models of soil C and N dynamics**
- **A nutrient resource threshold model for desired future ecosystem conditions based on soil N availability**
- **Data sets on soil carbon and nitrogen at Fort Benning for the SEMP Data Repository**
- **Posters and presentations; final report (ORNL/TM)**
- **Three (or more) peer reviewed articles that deal with soil quality indicators along disturbance gradients, differences in soil quality under different land covers, and nutrient threshold modelling**

Research Accomplishments

- *PRESENTATIONS*
  SEMP Research Coordination Meeting, Columbus, GA (11/00)
  ASA/CSSA/SSSA Meeting, Minneapolis, MN (11/00)
  SEMP Research Coordination Meeting, Columbus, GA (11/01)
- *POSTERS*
  Partners in Environmental Technology Technical Symposium and Workshop, Washington, DC (11/01)
- *JOURNAL ARTICLES*
  Effect of military training on indicators of soil quality at Fort Benning, GA (submitted to *Ecological Indicators*)
  Land cover differences in soil carbon and nitrogen at Fort Benning, Georgia (submitted to *Environmental Management*)
- *SEMP DATA REPOSITORY*
  Entered 2 data files dealing with studies of soil carbon and

Future Plans

- Continuing R&D on a nutrient threshold model including further comparisons with field data
- Collaborations with University of Florida
- Post-disturbance soil sampling at K-11 (Spring 2003)
- Integration of field data, GIS data, and modelling to predict landscape level PEN a
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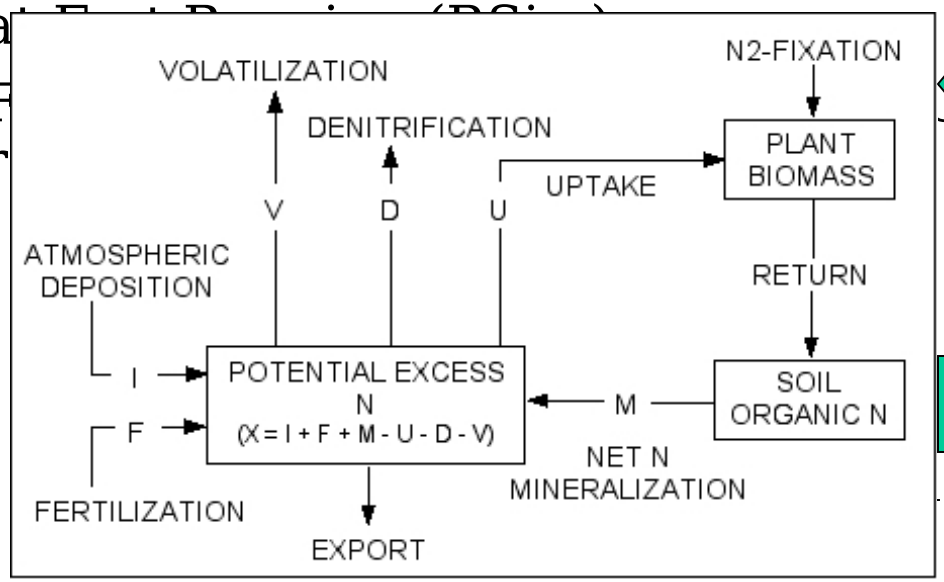
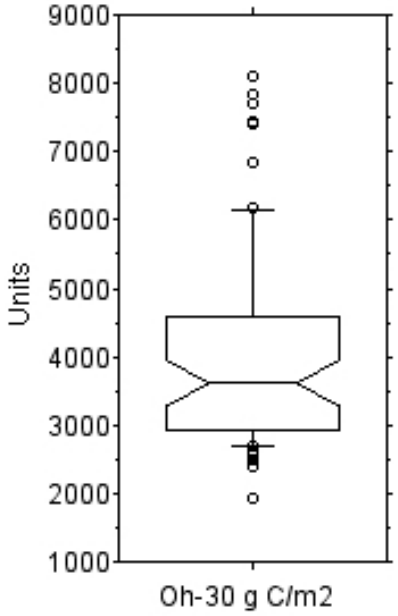
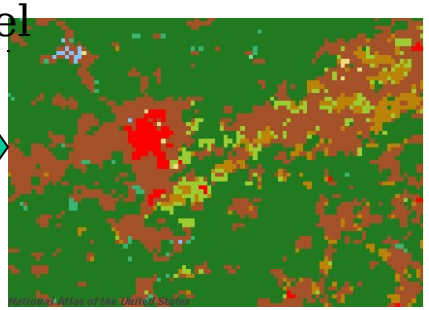


Field Data to Model

Forest Soil C
(n = 67)



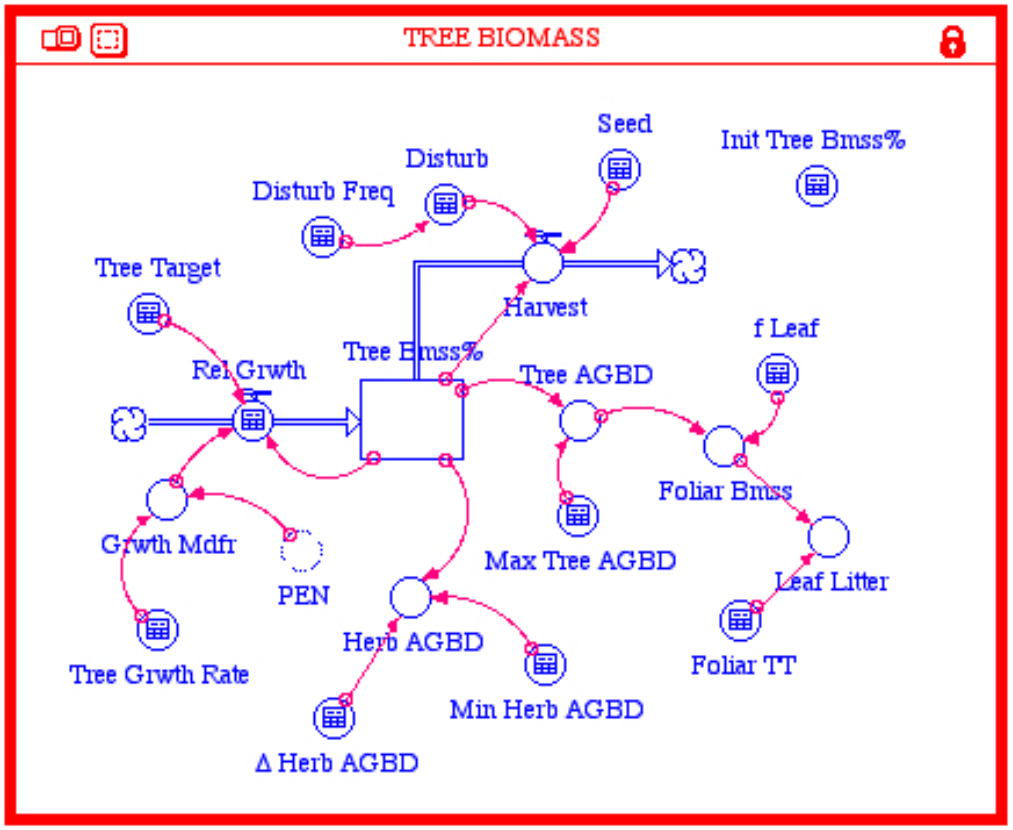
Model to Mapping



Extra Slides

- Stella(R) Model: Tree Biomass
- Stella(R) Model: Litter Production
- Stella(R) Model: Soil C & N Dynamics
- Stella(R) Model: N Demand & Excess N
- Progress Plan
- Research Funding

Stella(R) Model: Tree Biomass



"Relative growth" grows the forest to a designated desired future condition

- Tree target: 100%
- Tree growth rate: 0.15 yr^{-1}
- Growth modifier: IF PEN < 0.1 then 0 else "Tree Growth Rate"

"Harvest" removes the aboveground tree biomass

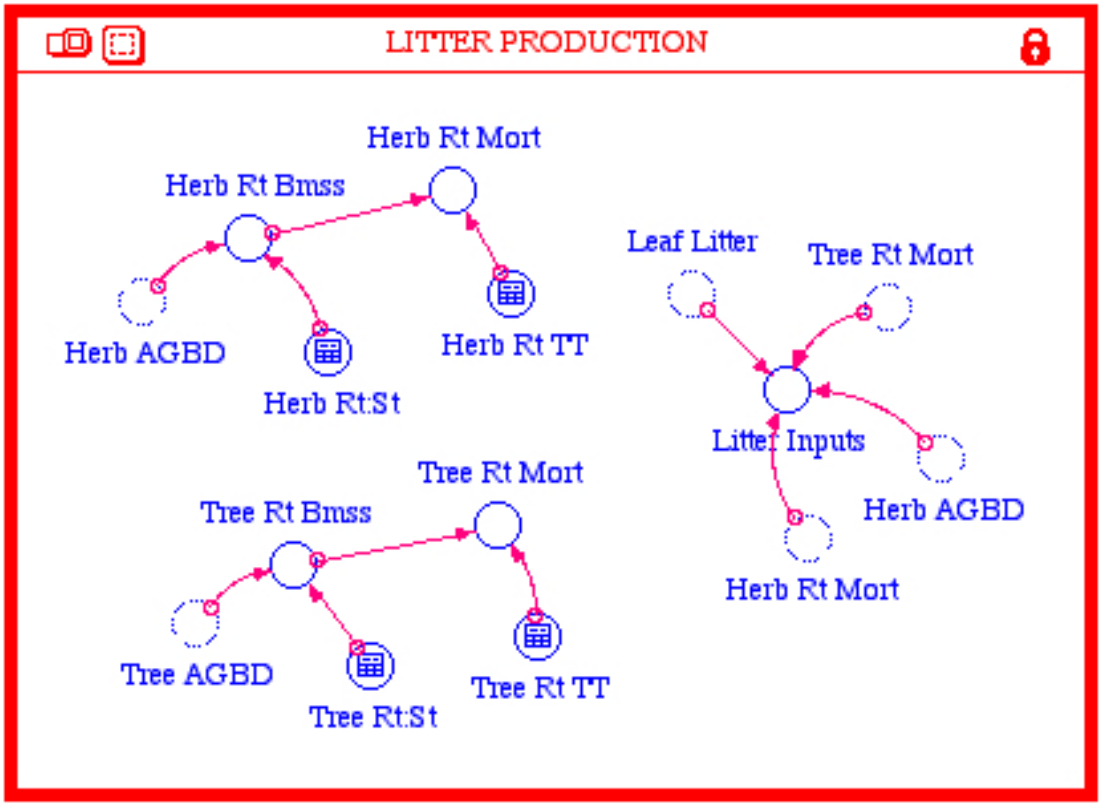
- Disturbance frequency
- "Seed" allows forest regrowth

Aboveground biomass density is calculated from a maximum and relative AGBD (%).

Foliar biomass is calculated based on a fraction of AGBD.

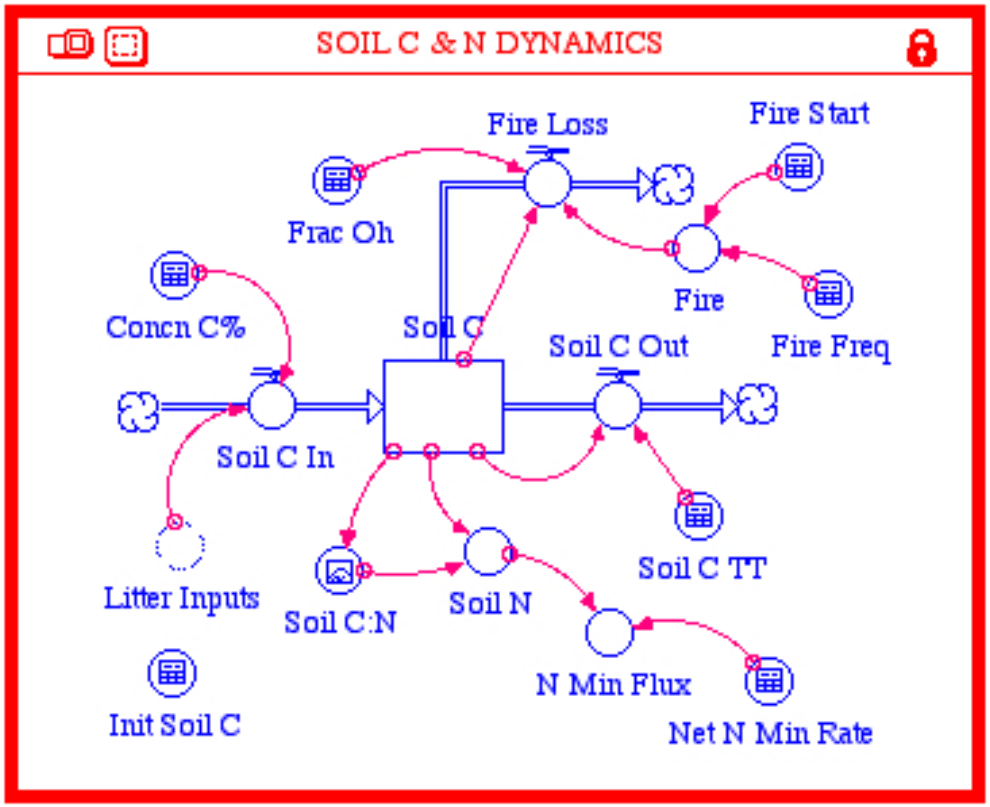
Foliar biomass contributes to leaf litter fall based on the turnover time of tree foliage.

Stella(R) Model: Litter Production



- Herb root and tree root biomass are calculated from respective root:shoot ratios.
- Herb root mortality and tree root mortality are calculated based on published estimates of root turnover time.
- Overstory leaf litter fall, annual production of aboveground herb biomass, tree root mortality, and herb root mortality all contribute litter inputs to soil organic matter.

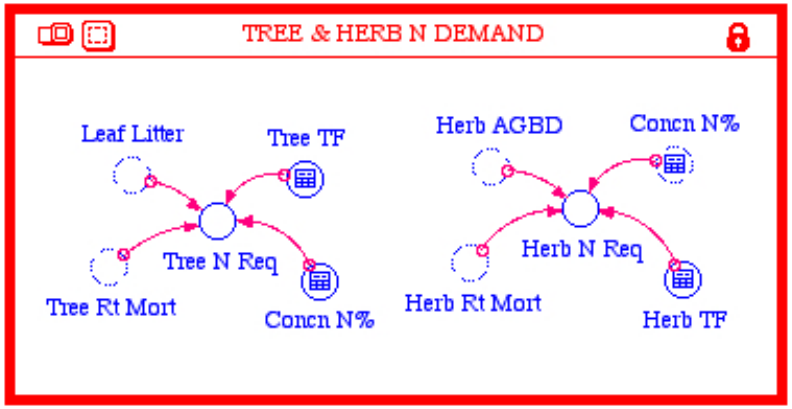
Stella(R) Model: Soil C & N Dynamics

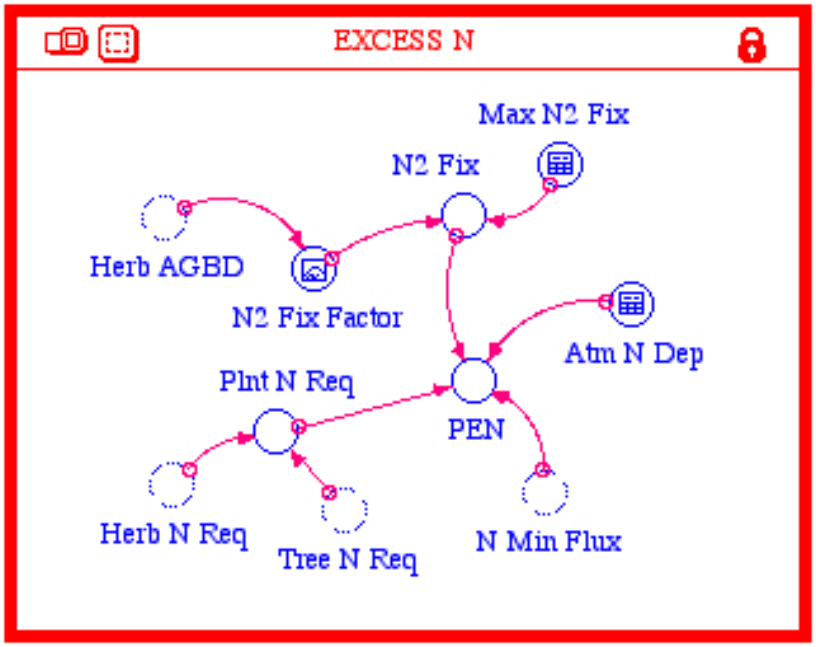


- "Soil C inputs" are calculated based on litter mass and C concentration.
- "Soil C outputs" represent decomposition losses and are calculated based on an estimated turnover time.
- "Fire loss" removes soil C (i.e., soil C in the O-horizon) at a specified fire frequency interval

- Soil N stocks are calculated based on the soil C:N ratio (which increases as a function of existing soil C stocks).
- The net soil N mineralization flux is calculated based on an annual rate and the calculated soil N stock.

Stella(R) Model: N Demand & Excess N





- Overstory and understory N requirements are calculated based on a tissue N concentration (1%), production of tree leaf biomass and herb aboveground biomass, and a translocation factor.
- Potential excess N (PEN) is the difference between the sum of 3 inputs (atmospheric N deposition, net soil N mineralization, and N_2-fixation) and 1 output (plant N requirement).
- N_2-fixation increases as a function of herbaceous

Progress Plan

ACTIVITY	FY 00				FY 01				FY 02				FY 03			
	1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st	2nd	3rd	4th
1. Field studies: military disturbance gradients (soil samples provided by Virginia Dale)	■	■	■	■	■	■										
2. Field studies: land cover differences (based on FB LCTA plots)		■	■	■	■	■	■	■	■	■	■					
3. Field studies: disturbance gradients, forest clear-cutting, site recovery (NRCS)							■	■	■	■	■	■	■	■		
4. Field studies: K11 (pre-treatment and post-treatment soil sampling at select locations)							■	■	■	■	■	■	■	■		
5. Field studies: longleaf pine chronosequence (to provide data for threshold modelling)											■	■	■	■		
6. Modelling: parameterize models of soil C and N for calculating thresholds to soil quality									■	■	■	■	■	■	■	■
7. Modelling: landscape level assessment of potential excess N (GIS + field data + modelling)													■	■	■	■